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FEDERAL COMMUNICATIONS
COMMISSION MEMORANDUM

Date: March 18, 2002

To: William Caton
Acting Secretary, FCC

From: Karl Kensinger
Special Advisor
Satellite and Radiocommunication Division
International Bureau

Re: IB Docket No. 02-54

Please include the attached materials in the public files for IB Docket No. 02-54. The attached materials are referred to in the Notice of Proposed Rule Making in this docket, FCC 02-80, adopted March 14, 2002. They consist of the following documents:

1. Physical Nature and Technical Attributes of the Geostationary Orbit, Study Prepared by the Secretariat, United Nations Committee on the Peaceful Uses of Outer Space, UN Document A/AC.105/404 (13 January 1988).
2. American Institute of Aeronautics and Astronautics, 6th International Space Cooperation Workshop Report (March 2001).
3. Letter dated February 11, 1998, from Daniel S. Goldin, Administrator, NASA, to William Kennard, Chairman, FCC.
4. Letter dated March 4, 1998, from Nicholas L. Johnson, NASA Chief Scientist for Orbital Debris, to Karl Kensinger, FCC International Bureau.
5. Nicholas L. Johnson, "Overview of NASA Orbital Debris Program," slides presented 27 January 1998 at the U.S. Government Orbital Debris Workshop for Industry.

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COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

PHYSICAL NATURE AND TECHNICAL ATTRIBUTES OF THE GEOSTATIONARY ORBIT

Study prepared by the Secretariat

CONTENTS

Annexes

I. BACKGROUND

1. In 1977, at the request of the Committee on the Peaceful Uses of Outer Space, a study was prepared on the physical nature and technical attributes of the geostationary orbit (A/AC.105/203). Additional and updated information has subsequently been published in a number of addenda to that report, most recently in 1983 (A/AC.105/203/Add.1-4).

2. The Committee on the Peaceful Uses of Outer Space, at its thirtieth session, in June 1987, endorsed the request of the Scientific and Technical Sub-Committee that the study continue to be brought up to date as required. The present report has been prepared, in response to the above request, by the Outer Space Affairs Division with the assistance of Mr. L. Perek, Mr. P. Lála and Mr. L. Sehnal of the Astronomical Institute of the Czechoslovak Academy of Sciences.

3. Since the Scientific and Technical Sub-Committee has before it several documents on the geostationary orbit, 1/ the present study has been restricted to the following topics: (a) a brief review of scientific aspects of the geostationary orbit; (b) a description of the present occupation of the orbit; (c) a discussion of space objects crossing the orbit; and (d) consideration of the accuracy of position determination in the orbit.

II. REVIEW OF SCIENTIFIC ASPECTS OF THE GEOSTATIONARY ORBIT

A. Definition of the geostationary orbit

4. The gravitational attraction of the Earth is the principal force determining the orbits of Earth satellites. This statement applies to all Earth satellites, whether they are in low or high orbits, in circular or eccentric orbits and whatever their period of revolution. What sets a geosynchronous or geostationary satellite apart from all other satellites is that its period of revolution is equal to the period of rotation of the Earth. Thus, internationally recognized definitions, appearing in the Radio Regulations of the International Telecommunication Union (ITU), 2/ state:

> Geosynchronous Satellite: An Earth satellite whose period of revolution is equal to the period of rotation of the Earth about its axis.
>
> Geostationary Satellite: A satellite, the circular orbit of which lies in the plane of the Earth's equator and which turns about the polar axis of the Earth in the same direction and with the same period as those of the Earth's rotation.
>
> Geostationary Orbit: The orbit on which a satellite should be placed to be a geostationary satellite.

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5. The period of the rotation of the Earth is with respect to an inertial reference system rather than to the Sun. It is the so-called sidereal period of 23 hours 56 minutes and 4 seconds, or, more accurately,

$$P = 1436.0683 \text{ minutes.}$$

6. Let us assume for a moment that the gravitational attraction of the Earth is the only force acting on the satellite and that the Earth is a perfect sphere. In such a case the motion of the satellite is given by a solution of the "two-body problem". The resulting orbit, in our case a circle centered on the centre of the Earth, does not change with time; the ground track of the satellite is a point on the Earth's equator and the satellite appears in a fixed direction from any point on the surface of the Earth where the satellite is above the horizon.

7. In reality, however, the attraction of the Earth is not the only force acting on the satellite and the Earth is not a perfect sphere. There are few problems in celestial dynamics where minor forces play such an important role as in the case of a satellite in the geostationary orbit.

B. Perturbations

8. "Perturbations" is a commonly used, but not quite accurately descriptive, term of celestial dynamics. It is used to refer to the consequences of the fact that the actual situation differs from the assumed simple conditions of the two-body problem. Let us list some of the most important additional forces which need to be considered in order to arrive at a more accurate description of actual satellite motion.

9. The oblateness of the Earth. The polar radius of the Earth is 21 km shorter than its equatorial radius. If we use the gravitational attraction of the oblate Earth, the laws of celestial mechanics determine the distance of the geostationary orbit from the centre of the earth to be

$$R = 42{,}164.697 \text{ km.}$$

The equatorial radius of the Earth is 6,378.140 km and consequently the difference of the two values, or the altitude of the geostationary orbit above the equator, is

$$A = 35{,}786.557 \text{ km.}$$

10. The attraction by the Moon and the Sun, together with the oblateness, exert a force on the satellite which pushes it out of the equatorial plane. This fact has been known to astronomers for a long time and was thoroughly studied in the nineteenth century in connection with the motion of the Moon. At the distance of the geostationary orbit, for small values of the eccentricity and inclination of a satellite orbit, there is one and only one stable solution to the equations of orbital motion 3/. It corresponds to an orbit inclined at 7.3° to the equator with a nodal regression period of about 54 years. The consequences for a satellite in the geostationary orbit are important. If the satellite is placed initially into an ideal equatorial geostationary orbit, its inclination will increase, initially

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by 0.86° per year, later more slowly, up to the value of 14.6° and then decrease back to zero. The cycle lasts one half of the nodal regression period, or about 27 years. Such motion, if unchecked, would carry the satellite out of its parking box, exceeding the variations permitted by the ITU rules.

11. Indeed, the inclination of all satellites in the geostationary orbit has been increasing since their last station-keeping corrections. Figure 1 (see annex I) shows the inclination of ATS-1, as it increased between 1968 and 1986.

12. The ellipticity of the equator. The difference between the largest and the smallest radius of the equator does not exceed 70 m, but it is enough to cause important deviations of a satellite in the geostationary orbit from its nominal position. The differences of the equatorial radii are rather irregular, but can, to a first approximation, be described by an ellipse, hence the term "ellipticity". Satellites oscillate in longitude around two stable points generally taken to be located at longitudes 75°E and 105°W, although Zhuravlev 4/ has proposed a more accurate value of 106.097° for the latter position. The period of oscillation is 2.3 years for small amplitudes and is longer for large ones. The resulting drift in longitude of a satellite is up to 0.4° per day. During westward drift the satellite is up to 34 km above the ideal geostationary orbit and the same amount below it during eastward drift. Because of the irregularities of the shape and mass distribution of the Earth, the oscillations are not quite symmetrical 5/. Examples are shown in figure 2 (see annex I) for three satellites in the time span 1973-1976.

13. Solar radiation pressure is the most important non-gravitational force acting on a satellite in the geostationary orbit. It causes a yearly oscillation of the orbital eccentricity and a rotation of the line of apsides. For a typical satellite the maximum eccentricity due to this effect is 0.006 and the maximum daily libration in longitude is 0.6°.

14. There are a number of other perturbations acting on a satellite in the geostationary orbit, but they do not substantially change the general picture presented above.

15. In summary, contrary to the general understanding that comes from a simplified approach to satellite orbits, the geostationary orbit is not a stable orbit. A satellite positioned in the geostationary orbit does not stay within the orbit if left to natural forces. The only truly stationary orbit, with respect to the attraction of the Earth, the Moon and the Sun, is an orbit with an inclination of 7.3°. Out of all longitudinal positions, only two would remain unchanged by forces arising from the ellipticity of the equator. Thus, natural forces, by themselves, do not allow for a strictly geostationary satellite.

C. Station-keeping

16. It is only thanks to station-keeping impulses that a satellite can be maintained within its "parking box" permitted by ITU rules. According to the rules in force, 6/ the actual position of a satellite may deviate by no more than 0.1° in

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longitude from its nominal position. In general, there is no regulatory constraint on the movements in the north-south direction, but many satellites are maintained within a tolerance of 0.1° in latitude in order to facilitate communication with ground stations. An exception to this rule is the broadcasting-satellite service for which satellites must be maintained in position with an accuracy better that ±0.1° in both the north-south and the east-west directions. In region 2 (the Americas), the tolerance in the north-south direction is recommended not required.

17. There is no regulation of movement in the radial direction and none is needed. Radial deviations follow from the laws of celestial mechanics and are, as a rule, smaller than those in the other directions. The parking box of a space station is illustrated in figure 3 (see annex I).

18. A satellite in the geostationary orbit cannot be thought of as "fixed in space". On the contrary, it is in permanent motion caused by both natural forces and occasional corrective impulses exerted by the satellites propulsion system. The satellite moves like a ball maintained in the air by skillful kicks of a football player's foot, as shown in figure 4 (see annex I). In the upper part of the figure, the longitudes of the INTELSAT 3 F-3 satellite have been plotted for the second half of 1979. The satellite, launched in 1969, was maintained within the tolerance which was in force at that time, i.e. within ±0.5° around its nominal position at 66.5°E. The arrows indicate that station-keeping impulses had to be applied every 3 months. The lower part of the same figure refers to the INTELSAT 4A F-6, launched in 1978, and maintained within the stricter limits of ±0.1°. The increased accuracy in station-keeping required corrective impulses every month.

19. East-west station-keeping, speaking from the point of view of celestial mechanics, can be done by impulses within the orbital plane. North-south station-keeping must be done by changing the orbital plane as shown in figure 5 (see annex I) and is much more demanding on fuel consumption, requiring about 10 times more fuel than east-west station-keeping.

20. There is one way to lessen the burden of station-keeping, save fuel and thereby increase the useful lifetime of a satellite. In the stationary circular geosynchronous orbit at inclination 7.3° no north-south station-keeping is necessary. The satellite appears from the ground to describe a double loop, or figure eight, between latitudes 7.3° north and south as shown in figure 6 (see annex I). The satellite moves through the double loop every 23 hours 56 minutes and 4 seconds. Most antennas, however, do not have beamwidths wide enough to accommodate the entire double loop of 14.6°. The need thus would arise for a movable antenna to track the satellite in its daily motion. The advantange of saving costs through a longer lifetime of the satellite would thus be offset by more expensive ground antennas. This is a matter for detailed economic calculations. Such systems have been proposed recently. 7/

21. Pushing the idea further, a satellite located at one of the two stable points in longitude, 105°W or 75°E, and with an inclination of 7.3° could dispense with both the north-south and the east-west station-keeping. A disadvantage would arise from crowding of satellites in a relatively small area of space.

22. Further improvements in station-keeping accuracy may be expected in the future. If they are accompanied by improvements in tracking accuracy, possibly by means of tracking from a nearby satellite, new avenues would open for the utilization of the geostationary orbit (see A/AC.105/203/Add.4, "Alternative orbits").

III. PRESENT OCCUPATION OF THE GEOSTATIONARY ORBIT

23. Since the first attempts to place a satellite into the geostationary orbit in 1963, the number of launchings into the geostationary orbit has been steadily increasing. Figure 7 (see annex I) shows that the increase was exponential up to the end of 1985 with 28 objects launched into the geostationary orbit in that year. Only 12 payloads were launched in 1986 and 9 payloads up to the end of October 1987, a consequence of the Challenger accident. Several satellites are waiting for a launching opportunity, and a rapid rise in the curve in figure 7 is to be expected in the future.

24. The following statistics concerning satellites in the geostationary orbit were compiled from the RAE Table of Earth Satellites 8/ and from other sources and refer to 31 October 1987:

Active satellites	179
Inactive satellites	56
Non-functional object	40
Total	275

25. Some satellites listed as "active" may have recently terminated their transmissions. About 10 satellites have been removed from the geostationary orbit. And, last but not least, the amount of debris in the geostationary orbit is unknown.

26. A list of space objects which are in the geostationary orbit or which come within 150 km of the ideal geostationary orbit appears in table 1 (see annex II).

27. The oldest active satellite is ATS-5, with the international designation 1969-069A, and there are a few active satellites among those launched in the mid-1970s. This is excellent performance since the design lifetime was 3 years in the 1960s, 7 years in the 1970s and only recently has been increased by some manufacturers to 10 years. Concerning the functions of satellites in the geostationary orbit, it can be estimated that about 16 per cent are used for research, experiment and meteorology, 16 per cent as national means of verification and early warning, and 68 per cent for communications.

28. Not all satellites launched into the geostationary orbit are still there. Some have been removed by operators, using the last supply of fuel carried on board for the purpose of station-keeping corrections. The first case of removal of a satellite from the geostationary orbit occurred in May 1977 when three INTELSAT 3 satellites (F-2, F-3 and F-3) were moved to higher disposal orbits at altitudes of 3,580 km, 3,700 km and 400 km respectively above the altitude of the geostationary

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orbit, orbits not used by any active satellites. In subsequent years, several other satellites were moved to disposal orbits, such as ATS 5, Raduga 5, Anik 1, SMS 1 and 2, INTELSAT 4 F-2 and F-4 and possibly others. In January 1984, the European Space Agency (ESA) raised the orbit of GEOS 2 (1978-071A) by 269 km above the geostationary orbit using only about 2 kg of fuel. 9/ The manoeuvre was elaborate, calling for three impulses. The small amount of fuel needed - a fraction of 1 per cent of the original 573 kg of fuel - proved that such manoeuvres are feasible without markedly reducing useful lifetimes. The removal of satellites into disposal orbits has apparently become a matter of policy with INTELSAT and ESA.

29. A recommendation calling for the systematic removal of satellites into disposal orbits toward the end of their active lifetimes was made as early as 1977. 5/ The matter was studied in some detail in one of the background papers (A/CONF.101/BP/7) of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) and a recommendation to follow this practice was included in the report of that Conference (see A/CONF.101/10 and Corr.1 and 2, para. 283).

30. Inactive satellites and non-functional objects in the table above are not the only undesirable objects affecting the geostationary orbit. There are also rocket stages and apogee motors in eccentric orbits which at times cross the geostationary orbit and at other times do not come close to it (see sect. IV below).

31. In addition, there is a certain amount of debris in the geostationary orbit, including detached shields, caps, bolts or flakes of paint. Their number is unknown, but there are indications that debris in the geostationary orbit cannot be neglected. With present tracking techniques, debris smaller than about 1 m cannot be detected at the altitude of the geostationary orbit.

32. From the point of view of ITU and the International Frequency Registration Board (IFRB), the present or planned occupation of the geostationary orbit presents a different picture. The following table gives the cumulative totals of communication satellites systems at various stages of ITU co-ordinating process as of the end of the year indicated.

	1979	1983	1985	1986
Geostationary satellite systems with advance publication	30	68	124	185
Systems in process of co-ordination	36	92	126	108
Systems co-ordinated and notified to the IFRB	82	83	137	164
Total	148	243	387	457

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33. The advance publication by a country is an announcement of intent to put into operation within five years a satellite communications system in the geostationary orbit. It is published in one of the circulars of IFRB.

34. After advance publication, the co-ordination of the new system with existing and planned systems is initiated with a view to preventing any harmful interference among transmissions. After a satisfactory conclusion of the co-ordinating procedure, relevant parameters of the system are notified to IFRB and entered into its Master Register.

35. A comparison of the two tables above shows that total numbers of existing and planned geostationary satellite systems, as indicated by the second table, have been increasing by more than 70 per year, much faster than the numbers of satellites actually launched into the geostationary orbit, which have not yet reached 30 per year, as indicated by the first table. The comparison also shows that the answer to a simple question "How many geostationary satellites are there?" depends on the point of view. The first table yields the correct answer for space objects actually launched into the geostationary orbit. The second table should be consulted for geostationary communication systems registered with IFRB.

36. As has been explained in document A/AC.105/203/Add.4, the registration of a satellite system in the Master Register of IFRB refers to an agreed orbital position of a communication system transmitting at a specified radio frequency, not to a physical space object itself. Indeed, one communication satellite may serve during its active lifetime at different assigned positions at different times, and different satellites may serve at different times at one assigned position. Whatever the specific arrangement, the operation of a station at an assigned orbital position and radiofrequencies is limited by the period of validity, which is one of the technical parameters of a satellite system appearing in IFRB Master Register. Other restrictions on the use of the orbital position and radiofrequencies may follow from the ITU Radio Regulations in force. 2/

IV. SPACE OBJECTS CROSSING THE GEOSTATIONARY ORBIT

37. This and the following section are intended to give additional background information on the danger of collisions involving satellites in the geostationary orbit. The main source of that danger is the inactive objects (see annex II, table 1) which are in or close to the geostationary orbit. They cut through the equatorial plane twice a day with a relative speed depending on the inclination of their orbits. These are, however, not the only objects that pass through the geostationary orbit. There are also discarded rocket stages which, after introducing the payload into the geostationary orbit and separating from it, remain in eccentric transfer orbits. There is also the large category of communication and early warning satellites in eccentric 12-hour orbits at high inclination, the so called Molniya-type orbits. Finally, there are scientific and applications satellites in special orbits extending beyond the geostationary orbit.

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A. Objects in transfer orbits

38. Every geostationary satellite has moved from a low Earth orbit into the geostationary orbit on an eccentric transfer orbit with a perigee of about 200 km altitude and an apogee around 36,000 km, slightly above the geostationary orbit. A discarded rocket body and possibly some fragments usually remain in the transfer orbit. The inclination of the transfer orbit depends on the geographical latitude of the launching site and is generally close to it. Thus, for each launching site there is a typical class of transfer orbits.

39. The Ariane rockets of ESA are launched from Kourou, French Guiana, at 5° latitude, into transfer orbits with an inclination of about 7°. The United States launches from Cape Canaveral at 28° latitude result in transfer orbit inclinations between 22° and 27°. Chinese and Japanese launchings use transfer orbits at 30° to 31° inclinations, while the Soviet Proton launcher uses orbits inclined at 47°, corresponding to the latitude of the Baikonur space centre.

40. In order for a spacecraft to reach the geostationary orbit, the apogee of the transfer orbit must be located close to the equatorial plane. The orbit, however, does not stay in that orientation for a long time since perturbations, as explained in section II.B above, cause a rotation of the orbit in its plane. The period of this "apsidal rotation" is 1.3 years for an orbital inclination of 7°, 1.8 years for an inclination of 30° and 3.7 years for that inclination of 47°. As a consequence of the apsidal rotation, an object in a transfer orbit crosses the geostationary orbit less than 5 per cent of the time.

41. The transfer orbit is affected by all perturbations discussed in section II.B and, in addition, by the atmospheric drag acting during its perigee passage. The main effect of the drag is the lowering of the apogee. As soon as the apogee altitude becomes less than the altitude of the geostationary orbit, the object stops crossing the geostationary orbit. Table 2 (see annex II), which lists all objects crossing through the geostationary orbit, shows that only a small number of old rockets and fragments still reach the geostationary altitude.

42. The detailed evolution of a transfer orbit is quite complicated. Perturbations due to the Sun and the Moon change its eccentricity, orientation and inclination to the equator. Consequently, the apogee altitude of a transfer orbit does not decrease steadily but varies periodically by about ±50 km. The average period of these variations is about nine months. The final effect in any specific case depends on the initial positions of the Moon, the Sun and the object in question. It may happen that the perigee altitude decreases rapidly and the objects decay in the dense layers of the atmosphere. On the other hand, a different combination of initial positions may lead to a lifetime more or less in agreement with the theory of atmospheric perturbations. As an illustration, the following table gives the lifetimes as predicted on the base of normal variations of atmospheric parameters:

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Perigee altitude	Lifetime
160 km	4-6 years
180 km	8-13 years
200 km	15-28 years
220 km	over 26 years

Accurate predictions of lifetimes can be done only on a case-by-case basis, and quite intricate computations are involved.

43. The objects listed in table 2 with low inclinations cross the geostationary orbit more frequently because of a faster apsidal rotation. Their relative velocity at encounter with satellites in the geostationary orbit is 1.5 km/s for 21° inclination and 2.3 km/s for 47° inclination. These speeds are about 6 to 10 times the speed of a jet plane.

44. Table 2 also includes objects with apogees slightly below the geostationary orbit since perturbations due to the Sun and the Moon may increase their altitudes so that they would pass through the geostationary orbit.

45. Compared to objects which are in or close to the geostationary orbit, objects in transfer orbit do not increase the collision probabilities substantially. However, they do need to be taken into account in studies of close approaches to specific satellites.

B. Satellites in Molniya-type orbits

46. Launches of Molniya communication satellites began in 1965. A total of 31 satellites have been launched with initial inclinations near 65°, perigee altitudes around 500 km and apogees over 39,000 km. They were accompanied by separate rocket stages in close, but slightly different, orbits, because the fine tuning of the orbital elements could be done by the station-keeping propulsion systems of the satellites. In 1973, the inclination was changed to 63° and this value has been retained for all subsequent Molniya and Cosmos satellites in this category.

47. The primary function of satellites in these orbits is to provide long-distance communications at high geographic latitudes. Thus, the apogee is located over the northern hemisphere and the perigee over the southern hemisphere. The angular distance of the perigee from the northbound equator crossing is 280° for communications and 320° for early warning satellites. These satellites therefore cross the equator plane far below the geostationary orbit. Only a considerable amount of apsidal rotation would bring the apogee of a Molniya satellite into the geostationary orbit.

48. The speed of apsidal rotation depends on inclination. In particular, there is no rotation for the critical inclination of 63.45°, close to the current inclination of Molniya-type orbits. Close to the critical value, the rotation is slow; its period at 63° is 210 years and at 65° is 60 years. These periods are

long compared to the lifetime of Molniya-type satellites which is less than seven years. 10/ Indeed all Molniya satellites launched before 1973 have already decayed. Lifetimes of the more recent Molniyas are 9 to 14 years, in some cases over 20 years.

49. As of 30 September 1987, there were 298 objects in stable Molniya-type orbits. All of them reach the distance of the geostationary orbit far from the equator and hence do not cross the geostationary orbit. Therefore they do not appear in table 2.

V. POSITION DETERMINATION FOR OBJECTS IN THE GEOSTATIONARY ORBIT

50. In investigating close approaches of satellites in the geostationary orbit, N. L. Johnson 11/ found that the uncertainty in determining accurate positions in the geostationary orbit was of the order of 10-20 km. This accuracy may still be sufficient for maintaining a satellite within its parking box of ±0.1° which is equivalent to ±74 km at the geostationary orbit. With several satellites at the same nominal position, a higher accuracy or co-ordinated station-keeping would be necessary to prevent close encounters or collisions among active satellites. An example of a shared longitude 12/ is the position at 19°W which has been allotted to about 10 prospective systems. Some authors 13/ are of the opinion that the probability of collision among active satellites is in such cases higher than the chance of an inactive satellite hitting an active one.

51. In this context, methods of accurate tracking of satellites in the geostationary orbit become important. Moreover, orbits of satellites with scientific missions, such as the determination of parameters of the Earth's gravity field, require an even higher accuracy of position determination. Thus, instead of the above 10-20 km, an accuracy of 600-800 m, or for scientific missions of 40-80 m, is needed. In angular measure, instead of 50-100 seconds of arc, the requirement is for a precision of 3-4 seconds of arc and in the extreme case, of 0.2-0.4 seconds of arc.

52. High accuracy in position determination can be achieved by several means, of which photography is a method presently and practically available. The main disadvantage of photography from the ground is, of course, the dependence on favourable weather conditions, but this does not present serious obstacles for a network of cameras at selected locations. An important advantage of photography is that inactive or non-functional objects are recorded just as well as active satellites.

53. Precise satellite photography has been done using the Baker-Nunn cameras which were operated in the first decade of the space era for tracking satellites in low orbits. Later, photographic monitoring was abandoned in favour of less cumbersome techniques which gave better results. For the geostationary orbit, however, it seems that photographic techniques will be reintroduced.

54. To attain the required accuracy, advanced photographic methods must be used, and a focal length about 1 m is required to provide a sufficiently large scale on the photographic plate. The position of the geostationary satellite must be measured with respect to stars whose positions are accurately known. Since the satellites move against the stars, and since a time-exposure is required, the camera has first to photograph the satellite, then the stars, each exposure in a different mode of motion. The motion is effected either by rotating the telescope or by a special movable plate-holder. The entire operation has to be timed to within 1 millisecond, or within 0.1 millisecond for the highest accuracy, and the precise time has to be recorded.

55. After exposure, the photographic plate is developed and measured and the positions of the satellite computed. An important point is the correct identification of individual objects, an easy task with respect to an isolated satellite with good station-keeping, but rather difficult if several satellites appear close together. In the latter case, consecutive photographs, possibly from different locations, may be needed to resolve the problem.

56. Several cameras capable of photographing satellites in the geostationary orbit are in operation. The English Hewitt cameras, situated at the Royal Greenwich Observatory at Herstmonceux Castle in the United Kingdom and at Siding Spring Mountain in Australia, have a focal length of 0.6 m and attain an accuracy of 1-3 seconds of arc, which is equivalent to 200-600 m at the geostationary orbit. A similar accuracy is achieved by the Soviet VAU cameras of the same focal length, located at Zvenigorod and Dushanbe Obervatories. The SBG cameras, manufactured in the German Democratic Republic, have a focal length of 0.76 m and achieve an accuracy of 2-3 seconds of arc. The same accuracy is obtained by the Soviet-made AFU-75 cameras with a focal length of 0.75 m. Astronomical astrographs, if equipped with adequate timing devices, are also excellent for this purpose. For example, the Zeiss Jena astrograph of the Kiev observatory in the Union of Soviet Socialist Republics, has a focal length of 2 m and provides measurements with an accuracy of 0.3-0.5 seconds of arc.

57. A new promising technique for determining positions of space objects is being developed using high sensitivity video cameras combined with video recorders to store the pictures. This technique has been used experimentally to monitor over 30 geostationary satellites. 14/

58. The methods for tracking objects in the geostationary orbit are developing rapidly and their accuracy is increasing. It is feasible, in principle, to design and operate tracking systems, either on the ground or in space, to permit safe operation of a cluster of satellites sharing the same nominal position.

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Notes

1/ "Physical nature and technical attributes of the geostationary orbit" (A/AC.105/203 and Add.1-4); "Efficient use of the geostationary orbit" (A/CONF.101/BP/7); "The feasibility of obtaining closer spacing of satellites in the geostationary orbit" (A/AC.105/340/Rev.1); annual reports of ITU on telecommunication and the peaceful uses of outer space; and annual reports of INTELSAT to the Committee on the Peaceful Uses of Outer Space.

2/ ITU, Radio Regulations (Edition 1982, Revised 1985), regulations RR1-22, RR1-23 and AP30-115.

3/ Y. Kozai, "The Motion of a Close Earth Satellite", Smithsonian Astrophysical Observatory, Special Report 349 (1973).

4/ P. G. Zhuravlev, Astronomicheskyi Zhurnal, vol. 54, (1977), p. 909.

5/ L. Perek, "Physics, uses and regulation of the GSO" (IAF Congress, Prague 1977), paper IAF-SL-77-44. See also A/AC.105/203 and Add.1-4. For explanation of the asymmetry of oscillations, see M. Sidlichovsky "Note on the shift of the center of libration of geosnychronous satellites", Bull. Astron. Inst. Czechosl. 30 (1979), p. 41.

6/ Final Acts of the WARC-ORB 85, Appendix 30, para. 3.11.

7/ D. E. Snager, "Longer life for orbiting satellites at hand, easing launching needs", The New York Times, 17 October 1986, p. A1.

8/ Royal Aircraft Establishment, Farnborough, U.K. Issued monthly.

9/ P. Beech, M. Soop, J. van der Ha, "The de-orbiting of GEOS 2", ESA Bulletin No. 38 (1985), p. 86.

10/ D. G. King-Hele, D. M. C. Walker, "The prediction of satellite lifetimes", Technical Report 87030 (Royal Aircraft Establishment, Farnborough, U.K., May 1987).

11/ N. L. Johnson, "The crowded sky", Spaceflight 1982, vol. 24, p. 446.

12/ E. M. Soop, "Orbital control of geostationary spacecraft from dedicated control centres", ESA Bulletin No. 52 (November 1987) p. 42.

13/ G. Fusco, A. Buratti, "Crowding of the geostationary orbit", ESA Contract Report No. 5705/83/NL/PP/Sc (1984).

14/ P. D. Maley, "Television ground-tracking applied to aerospace and astronomical events" (IAF Congress, Innsbruck, 1986), paper IAF 86-305.

Annex I

FIGURES

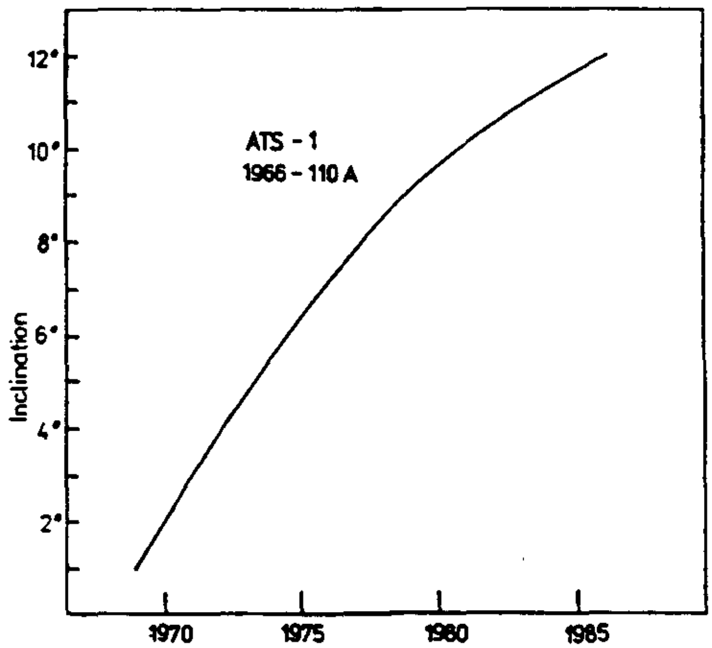

Figure 1. The inclination of ATS-1 as it increased between 1968 and 1986.

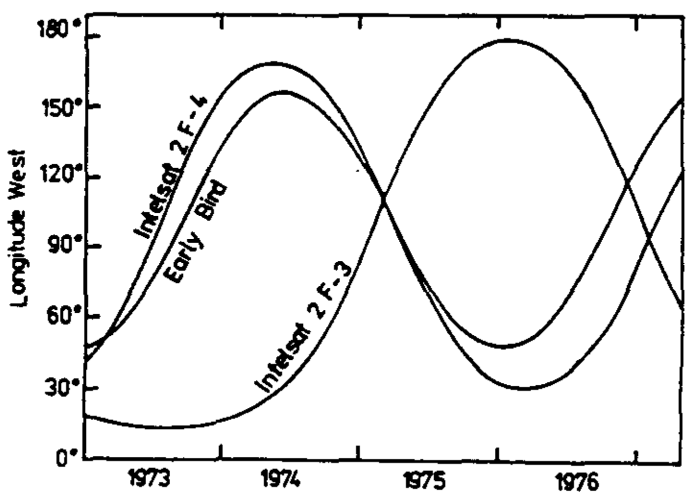

Figure 2. Oscillations in Longitude of satellites with no station-keeping.

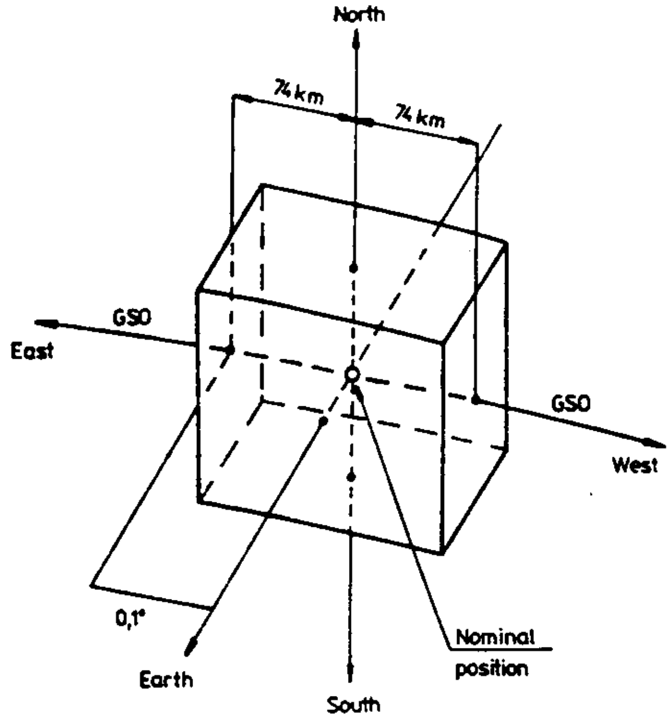

Figure 3. The "parking box" defines the permitted deviations of a satellite in the GSO from its nominal position.

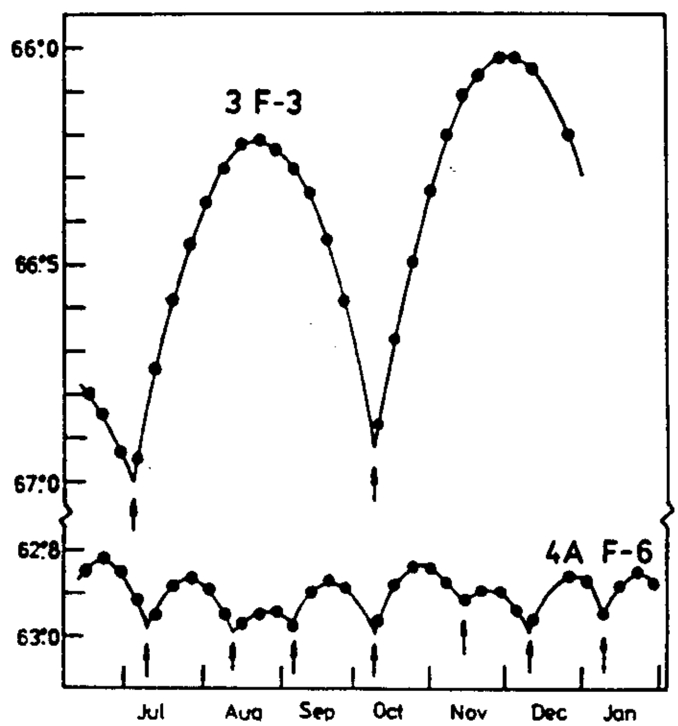

Figure 4. East-West station-keeping of two INTELSAT satellites with respective tolerances of ± 0.5° and ±0.1°.

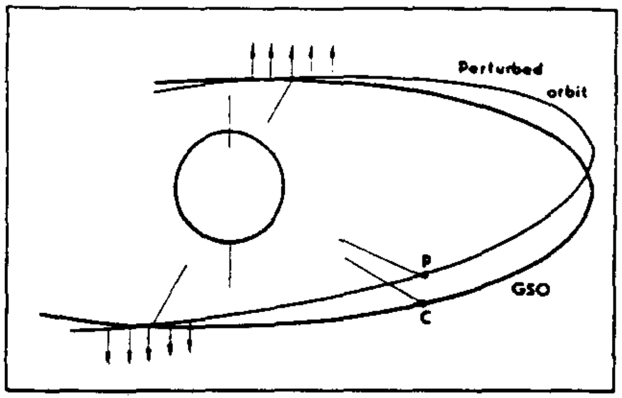

Figure 5. North-South station-keeping requires a change of the orbital plane by impulses timed around the equator passages.

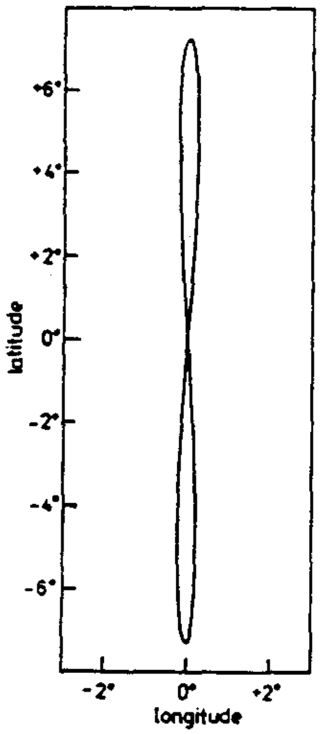

Figure 6. Sky-track of a satellite in the stationary geosynchronous orbit at 7.3° inclination.

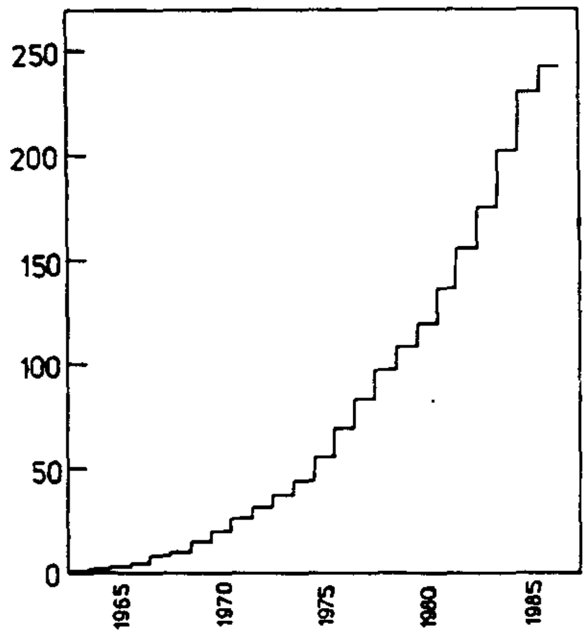

Figure 7. The number of payloads launched into the GSO between 1963 and 1986.

Annex II

TABLES

Table 1

LIST OF SPACE OBJECTS IN OR CLOSE TO THE GEOSTATIONARY ORBIT

Table 1 lists space objects, including active and inactive satellites and non-functional objects, in circular or near-circular orbits which cross an orbital band extending 150 km above and below the ideal geostationary orbit.

The first column gives the international designation assigned to space objects by COSPAR. The second column gives the launching country or agency using the abbreviations used in ITU annual reports to the United Nations Committee on the Peaceful Uses of Outer Space. The third column gives the launching name of a payload or a descriptive term of a non-functional object. Payloads and non-functional objects launched together have the same COSPAR numbers, but are distinguished by a following letter.

The following columns give the orbital inclination in degrees and the orbital position in degrees East (E) or West (W) of the Greenwich meridian on the day shown in column headed "Epoch". The first two digits of the epoch give the month and the last two digits the day of determination of the inclination and orbital position. Inclinations appearing without corresponding orbital positions have been taken from the Satellite Situation Report No. 27 of NASA.

The last column contains the symbol I, "inactive", for non-functional objects and for payloads which have ceased their transmissions according to the RAE Table of Earth Satellites. Most, but not necessarily all, of the remaining payloads were active in October 1987.

Sources: Satellite Situation Report, Vol. 27, Nos. 2 and 3 (Goddard Space Flight Center, NASA, 1987).

"World Data Center A for Rockets and Satellites", Spacewarn Bulletin (Goddard Space Flight Center, Greenbelt, Maryland, USA). Issued monthly.

Geosynchronous Satellite Report (Project Operations Branch, Goddard Space Flight Center, NASA) 1 July and 1 October 1987.

RAE Table of Earth Satellites (Royal Aircraft Establishment, Farnborough, U.K.). Issued monthly.

Table 1 (continued)

COSPAR No.	Country Agency	Name	Incli-nation Degrees	Orbital position Degrees	Epoch	Remark
1963-031A	USA	Syncom 2				I
1964-047A	USA	Syncom 3				I
1965-028A	USA	Early Bird				I
1967-001A	USA IT	Intelsat 2 F-2				I
026A	USA IT	Intelsat 2 F-3				I
094A	USA IT	Intelsat 2 F-4				I
111A	USA	ATS 3	11.9	105.3W	0928	I
1968-063A	USA	BMEWS I-1				I
081C	USA	ERS-21				I
081D	USA	LES 6	9.7			I
081E	USA	Transtage	9.5			I
1969-013A	USA	Tacsat 1				I
036A	USA	BMEWS 2				I
069A	USA	ATS 5	9.5			
101A	G	Skynet 1A				I
1970-021A	NATO	NATO 1	9.6	107.6W	0928	I
032A	USA IT	Intelsat 3 F-7				I
069A	USA	BMEWS 4				I
1971-000E	?	Fragment				I
009A	NATO	NATO 2	8.7			I
039A	USA	IMEWS 2				I
039B	USA	Transtage				I
095A	USA	DSCS 1	9.5	108.4W	0928	I
095B	USA	DSCS 2	9.2			I
116A	USA IT	Intelsat 4 F-3	3.9			I
1972-041A	USA IT	Intelsat 4 F-5	5.8			I
101A	USA	BMEWS 5				I
1973-013A	USA	BMEWS 6				I
023A	CAN	Anik A2	4.6			I
040A	USA	IMEWS 4				
058A	USA IT	Intelsat 4 F-7	6.0			I
100A	USA	DSCS 3	7.7			I
100B	USA	DSCS 4	9.2	81.2E	0729	I
1974-017A	URS	Cosmos 637	7.2			I
017F	URS	Apogee motor	9.2			I
022A	USA	Westar 1				
039C	USA	Rocket /ATS 6/	8.4			I
075A	USA	Westar 2	3.9			
093A	USA IT	Intelsat 4 F-8	3.0			
094A	G	Skynet 2B	7.6	30.8E	0729	
101A	F SYM	Symphonie 1	3.6			
1975-038A	CAN	Anik A3	3.2			
042A	USA IT	Intelsat 4 F-1	3.3	58.7W	1001	
055A	USA	BMEWS				I
077A	F SYM	Symphonie 2	7.7			
091A	USA IT	Intelsat 4A F-1	2.9			
097A	URS	Cosmos 775	9.0	82.3E	0811	I
097F	URS	Apogee motor	8.9			I
100A	USA	GOES 1	7.3	125.4W	0928	I
117A	USA	RCA Satcom 1	3.2			
118A	USA	IMEWS 5				
118C	USA	Transtage				I
1975-118D	USA	Fragment				I
123A	URS	Raduga 1				I
1976-004A	CAN	Anik C2	7.7			I
010A	USA IT	Intelsat 4A F-2	3.3			
017A	USA	Marisat 1	6.3	14.6E	1001	
023A	USA	LES 8	21.8			
023B	USA	LES 9	21.7			
023F	USA	Transtage	22.1			I

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Table 1 (continued)

COSPAR No.	Country Agency	Name	Incli- nation Degrees	Orbital position Degrees	Epoch	Remark
035A	NATO	NATO 3A	6.0	29.5W	0925	
042A	USA	Comstar 1	3.1			
053A	USA	Marisat 2	5.1	72.6E	1001	
059A	USA	IMEWS 6				
059C	USA	Transtage				I
066A	INS	Palapa 1	0.8			I
073A	USA	Comstar 2	3.2	76.9W	1001	
092A	URS	Raduga 2				I
092F	URS	Apogee motor	8.1			I
101A	USA	Marisat 3	6.7	176.2E	1001	
107A	URS	Ekran 1	8.0			I
1977-005A	NATO	NATO 3B	4.7	67.3W	0622	
007A	USA	IMEWS 7				
007C	USA	Transtage				I
014A	J	Kiku 2 = ETS 2	6.5	129.9E	0710	
018A	INS	Palapa 2	3.4			
034B	USA	DSCS 2-8	6.5	0.3W	0925	
034C	USA	Transtage	6.8			I
041A	USA IT	Intelsat 4A F-4	2.2	21.5W	1001	
048A	USA	GOES 2	5.5	113.4W	0909	
065A	J	Himawari 1	5.8	159.3E	0926	
071A	URS	Raduga 3	7.8	38.7E	0927	I
071F	URS	Apogee motor	7.8			I
080A	I	Sirio 1	3.8			
108A	F MET	Meteosat 1	6.8	61.6E	0927	
1978-002A	USA IT	Intelsat 4A F-3	1.7	177.1E	1001	
016A	USA	Fltsatcom 1	5.8	178.5W	0929	
035A	USA IT	Intelsat 4A F-6	1.5	56.8E	0625	
039A	J	Yuri 1	4.5			
044A	F OTS	OTS 2	3.8	4.7E	0909	
058A	USA	IMEWS 8				
062A	USA	GOES 3	4.4	129.6W	0911	
073A	URS	Raduga 4				I
106A	NATO	NATO 3C	2.5	17.1W	0527	
113A	USA	DSCS 11 /Type 2/	4.4	129.8W	0928	
113B	USA	DSCS 12 /Type 2/	4.2	61.4E	0920	
116A	CAN	Anik B-1	0.8			
1979-015A	URS	Ekran 3	6.5			I
035E	URS	Apogee motor /Raduga 5/	6.5			I
038A	USA	Fltsatcom 2	4.2			
053A	USA	IMEWS 9				
053C	USA	Transtage				I
062A	URS	Gorizont 2	6.2	85.2E	0921	I
072A	USA	Westar 3	0.0	90.8W	0923	
1979-086A	USA	IMEWS 10				
086C	USA	Transtage				I
087A	URS	Ekran 4	1.0			I
087E	URS	Apogee motor				I
098A	USA	DSCS 13 /Type 2/	3.9	174.7E	0926	
098B	USA	DSCS 14 /Type 2/	3.9	179.1W	0929	
098C	USA	Transtage	4.8			I
105A	URS	Gorizont 3	5.9	39.7E	0927	I
1980-004A	USA	Fltsatcom 3	4.1	22.5W	0925	
016A	URS	Raduga 6	6.1	62.3E	0908	I
018A	J	Ayame 2	0.5			I
049A	URS	Gorizont 4	5.6	11.2W	0930	I
074A	USA	GOES 4	3.9	43.2W	0923	
081A	URS	Raduga 7	5.4			I
081F	URS	Apogee motor	5.5			I

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Table 1 (continued)

COSPAR No.	Country Agency	Name	Incli- nation Degrees	Orbital position Degrees	Epoch	Remark
087A	USA	Fltsatcom 4	3.8	171.6E	0928	
091A	USA	SBS 1 /F-3/	0.4	99.0W	0928	
098A	USA IT	Intelsat 5 F-2	0.0	1.0W	1001	
104A	URS	Ekran 6	5.5	55.6E	0927	I
1981-018A	USA	Comstar 4	1.6	75.9E	1001	
025A	USA	IMEWS 11				
027A	URS	Raduga 8	5.2			I
049A	USA	GOES 5	0.9	108.2W	0923	
050A	USA IT	Intelsat 5 F-1	0.0	174.1E	1001	
057A	F MET	Meteosat 2	0.9	0.9W	0924	
057B	IND	ISCOM Apple	0.8			I
061A	URS	Statsionar-Ekran 7	5.2	57.1E	0927	I
069A	URS	Raduga 9	5.0	103.3E	0907	I
073A	USA	Fltsatcom 5	4.4			
076A	J	Himawari 2 = GMS 2	3.5	119.6E	0924	
096A	USA	SBS 2 /F-1/	0.0	97.1W	0928	
102A	URS	Raduga 10	4.9	85.6E	0929	I
102F	URS	Apogee motor	4.7			I
107A	USA	IMEWS 12				
107C	USA	Transtage				I
114A	USA	RCA Satcom 3R	0.0	131.0W	0917	
119A	USA IT	Intelsat 5 F-3	0.1	53.0W	1001	
122A	F MRS	Marecs 1	1.6	177.9E	0927	
1982-004A	USA	RCA Satcom 4	0.1	75.5W	0907	
009A	URS	Statsionar-Ekran 8	4.4			I
009F	URS	Apogee motor	4.3			I
014A	USA	Westar 4	0.0	98.9W	0928	
017A	USA IT	Intelsat 5 F-4	0.1	34.3W	1001	
019A	USA	IMEWS 13				
020A	URS	Gorizont 5	4.4	96.1E	0928	
031A	IND	INSAT 1A	0.1			I
044A	URS	Cosmos 1366	4.1	80.4E	1001	I
044F	URS	Apogee motor	3.8			I
058A	USA	Westar 5	0.0	122.6W	0930	
082A	CAN	Anik D-1	0.0	104.5W	0921	
093A	URS	Statsionar-Ekran 9	1.7			
097A	USA IT	Intelsat 5 F-5	0.0	62.9E	1001	
1982-103A	URS	Gorizont 6	3.7	139.8E	0930	
103E	URS	Apogee motor	3.3			I
105A	USA	RCA Satcom 5	0.0	142.7W	0923	
106A	USA	DSCS 15 /Type 2/	2.0	17.2W	0715	
106B	USA	DSCS 16 /Type 3/	0.0	134.8W	0929	
106D	USA	Inertial Uppoer Stage	1.9			I
110B	USA	SBS 3 /F-2/	0.0	95.1W	0928	
110C	CAN	Anik C3	0.0	117.5W	0921	
113A	URS	Raduga 11	3.1	35.1E	0930	
1983-006A	J	Sakura 2A	0.0	126.6E	0718	
026B	USA	TDRS 1	2.0	40.9W	0928	
028A	URS	Raduga 12	2.8	69.8E	0908	
028F	URS	Apogee motor	2.6			I
030A	USA	RCA Satcom 6 /1R/	0.0	138.3W	0925	
041A	USA	GOES 6	0.0	135.3W	0919	
047A	USA IT	Intelsat 5 F-6	0.0	18.5W	1001	
058A	F EUT	ECS 1 = Eutelsat 1 F-1	0.4	13.2E	0927	
059B	CAN	Anik C2 = Telesat 7	0.0	110.0W	0921	
059C	INS	Palapa B1	0.0	106.7E	0902	
065A	USA	Galaxy 1	0.0	134.0W	0901	

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Table 1 (continued)

COSPAR No.	Country Agency	Name	Incli- nation Degrees	Orbital position Degrees	Epoch	Remark
066A	URS	Gorizont 7	2.5	11.4W	1001	
077A	USA	Telstar 3A	0.0	96.0W	0918	
081A	J	Sakura 2B	0.1	135.7E	0914	
088A	URS	Raduga 13	2.2	65.2E	0930	
089B	IND	INSAT 1B	0.1			
094A	USA	RCA Satcom 7 /2R/	0.1	72.1W	0928	
098A	USA	Galaxy 2	0.0	74.0W	0830	
100A	URS	Statsionar-Ekran 11	3.3	54.6E	0928	
105A	ESA IT	Intelsat 5 F-7	0.0	66.0E	1001	
118A	URS	Gorizont 8	1.9			
118F	URS	Apogee motor	1.8			I
1984-005A	J	Yuri 2A = BS 2A	0.1	109.8E	0924	
016A	URS	Raduga 14	2.1	86.9E	1001	
016F	URS	Apogee motor	1.8			I
022A	URS	Cosmos 1540	2.8	80.4E	0928	
022F	URS	Apogee motor	2.6			I
023A	ESA IT	Intelsat 5 F-8	0.1	180.0E	1001	
028A	URS	Statsionar-Ekran 12	4.2	90.3E	0928	
031A	URS	Cosmos 1546	1.7			
035A	CHN	China 15	1.2	125.5E	0902	
037A	USA	IMEWS or DSCS ?	1.3			
037B	USA	Transtage rocket	1.3			I
041A	URS	Gorizont 9	1.8	90.7E	0928	
049A	USA	Spacenet 1	0.0	120.0W	0928	
063A	URS	Raduga 15	1.8	128.5E	0927	
078A	URS	Gorizont 10	1.5	80.2E	0930	
078F	URS	Apogee motor	1.2			I
080A	J	Himawari 3 = GMS 3	0.9	139.9E	0909	
081A	F EUT	ECS 2=Eutelsat 1 F-2	0.1	7.1E	0924	
081B	F	Telecom 1A	0.0	8.7W	0929	
090A	URS	Statsionar-Ekran 13	2.1			
093B	USA	SBS 4 /F-4/	0.0	91.0W	0928	
1984-093C	USA	Syncom 4-2 = Leasat 2	0.0	176.5W	0831	
093D	USA	Telstar 3C	0.0	86.0W	0917	
101A	USA	Galaxy 3	0.0	93.5W	0901	
113B	CAN	Anik D2 = Telesat 8	0.0	110.5W	0921	
113C	USA	Syncom 4-1 = Leasat 1	0.0	15.4W	0823	
114A	USA	Spacenet 2	0.0	69.0W	0730	
114B	F MRS	Marecs 2	2.0	26.0W	0927	
115A	NATO	NATO 3D	3.6	21.7W	0728	
129A	USA	USA 7	3.4			
129B	USA	Transtage rocket	3.4			I
1985-007A	URS	Gorizont 11	1.0	53.2E	0928	
010B	USA	USA 8				
014A	USA	USA 9				
015A	ARSARB	Arabsat 1A	0.2			
015B	B	Brasilsat 1	0.0	65.1W	0927	
016A	URS	Cosmos 1629	1.1	66.5W	0822	
016F	URS	Apogee motor	0.8			I
024A	URS	Ekran 14	1.9	99.8E	1001	
025A	USA IT	Intelsat 5A F-10	0.0	24.5W	1001	
028B	CAN	Anik C1 = Telesat 9	0.6	107.5W	0921	
028C	USA	Syncom 4-3 = Leasat 3	0.0	104.2W	0828	
035A	ESA	GSTAR 1	0.0	103.0W	0922	
035B	F	Telecom 1B	1.5	8.7E	0527	
048B	MEX	Morelos 1	0.1	113.5W	0928	
048C	ARSARB	Arabsat 1B	0.0	26.4E	0914	
048D	USA	Telstar 3D	0.0	125.0W	0913	

Table 1 (continued)

COSPAR No.	Country Agency	Name	Incli- nation Degrees	Orbital position Degrees	Epoch	Remark
055A	USA IT	Intelsat 5A F-11	0.0	27.4W	1001	
070A	URS	Raduga 16	0.7	171.0W	0929	
076B	AUS	Aussat 1	0.0	160.0E	0907	
076C	USA	ASC 1	0.1	127.4W	0902	
076D	USA	Syncom 4-4 = Leasat 4	0.0	179.0W	0417	
087A	USA IT	Intelsat 5A F-12	0.1	60.0E	1001	
092B	USA	USA 11				
092C	USA	USA 12				
092E	USA	Inertial Upper Section				I
102A	URS	Cosmos 1700	0.4	55.8E	0921	
102D	URS	Apogee motor	0.1			I
107A	URS	Raduga 17	0.5	34.4E	0929	
109B	MEX	Morelos 2	1.3	116.4W	0927	
109C	AUS	Aussat 2	0.0	156.0E	0925	
109D	USA	Satcom K2	0.1	81.1W	0930	
1986-003B	USA	Satcom K1	0.0	85.0W	0929	
007A	URS	Raduga 18	0.3	24.5W	0930	
010A	CHN	China 18	0.1	103.2E	0920	
016A	J	Yuri 2B = BS 2B	0.1	109.8E	0919	
026A	USA	GSTAR 2	0.0	104.9W	0907	
026B	B	Brasilsat 2	0.1	76.7W	0929	
027A	URS	Cosmos 1738	0.5	13.2W	1001	
038A	URS	Ekran 15	0.9	99.7E	0930	
044A	URS	Gorizont 12	0.2	14.5W	0930	
082A	URS	Raduga 19	0.5	46.0E	0929	
090A	URS	Gorizont 13	0.6	90.2E	0930	
1986-090D	URS	Apogee motor	0.9			I
096A	USA	Fltsatcom 7	4.9			
1987-022A	USA	GOES 7	0.1	74.7W	0928	
028A	URS	Raduga 20	0.9	85.4E	0929	
028D	URS	Apogee motor	1.1			I
029A	INS	Palapa B-2P	0.0	113.1E	0925	
040A	URS	Gorizont 14	1.2	140.0E	0921	
070A	J	Kiku 5 = ETS 5	0.1	150.3E	0916	
073A	URS	Ekran 16	0.4	99.4E	0930	
078A	AUS	Aussat K3	0.1	164.0E	0927	
078B	F EUT	ECS 4=Eutelsat 1 F-4	0.2			
084A	URS	Cosmos 1888	1.4			
084D	URS	Fourth stage	1.7			I
091A	URS	Cosmos 1894	1.4			
091D	URS	Fourth stage	1.3			I

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Table 2

LIST OF SPACE OBJECTS IN ECCENTRIC ORBITS CROSSING
THE DISTANCE OF THE GEOSTATIONARY ORBIT

Table 2 lists space objects whose perigees are below and apogees above the geostationary orbit.

The first two columns have the same arrangement as in table 1. The third column contains names of payloads or descriptive terms of non-functional objects followed by the name of the associated payload.

The following columns give the orbital period of the space object in minutes, the inclination of the orbit in degrees, and the apogee and perigee altitudes.

Sources: RAE Table of Earth Satellites (Royal Aircraft Establishment, Farnborough, U.K.). Issued monthly.

Satellite Situation Report, Vol. 27, Nos. 2 and 3 (Goddard Space Flight Center, NASA, 1987).

"World Data Center A for Rockets and Satellites", Spacewarn Bulletin (Goddard Space Flight Center, Greenbelt, Maryland, USA). Issued monthly.

Table 2 (continued)

COSPAR No.	Country Agency	Name	Period Minutes	Inclination Degrees	Apogee km	Perigee km
1966-096A	USA	Intelsat 2 F-1	718.4	16.9	37201	3181
110A	USA	ATS 1	1434.5	12.0	42271	29236
1967-001X	USA	Fragment /Intelsat 2 F-2/	656.9	27.8	36653	652
1969-069B	USA	Rocket /ATS 5/	703.3	17.2	37362	2275
069C	USA	Fragment /ATS 5/	682.2	17.2	36497	2086
1970-093A	USA	IMEWS 1	1198.1	14.5	36038	25939
093B	USA	Transtage	1197.8	14.5	36050	25912
1971-006B	USA	Rocket /Intelsat 4 F-2/	653.8	27.3	36579	569
1972-003B	USA	Rocket /Intelsat 4 F-4/	653.6	28.0	36502	636
041B	USA	Rocket /Intelsat 4 F-5/	651.8	27.0	36491	555
1973-058B	USA	Rocket /Intelsat 4 F-7/	653.4	27.4	36631	498
1974-093B	USA	Rocket /Intelsat 4 F-8/	653.2	25.8	36471	646
101G	USA	Rocket /Symphonie 1/	665.3	12.9	37313	418
1975-042B	USA	Rocket /Intelsat 4 F-1/	654.2	26.2	36591	576
077C	USA	Fragment /Symphonie 2/	654.4	13.8	36765	416
091B	USA	Rocket /Intelsat 4A F-1/	654.1	21.5	36716	449
123F	URS	Fragment /Raduga 1/	1339.1	0.3	40108	27625
1976-010B	USA	Rocket /Intelsat 4A F-2/	654.4	21.8	36574	608
042B	USA	Rocket /Comstar 1/	648.8	21.5	36261	633
073B	USA	Rocket /Comstar 2/	646.9	21.3	36282	517
1977-029A	ESA	ESA GEOS	734.1	26.0	38553	2604
041B	USA	Rocket /Intelsat 4A F-4/	648.8	21.1	36342	550
1978-002B	USA	Rocket /Intelsat 4A F-3/	650.6	20.8	36375	612
012A	ESA	IUE	1436.4	30.6	43294	28290
012C	USA	Rocket	673.5	29.2	37839	306
035B	USA	Rocket /Intelsat 4A F-6/	648.5	21.4	36224	656
068B	USA	Rocket /Comstar 3/	649.3	22.1	36292	626
118A	URS	Gorizont 1	1436.4	15.0	50810	20773
118C	URS	Rocket	1417.4	14.9	50181	20657
1979-007A	USA	Scatha	1415.7	5.2	42511	28261
009A	J	Ayame 1	1314.5	0.7	37548	29194
1980-060A	URS	Ekran 5	1438.4	9.6	69711	1953
1981-018B	USA	Rocket /Comstar 4/	650.3	20.2	36340	630
1982-110D	USA	Rocket /SBS 3/	654.9	23.0	36847	357
110E	USA	Rocket /Anik C3/	654.3	22.8	36822	354
1983-020A	URS	Astron 1	5915.8	79.8	178817	25128
059E	USA	Rocket /Palapa 3/	662.1	25.6	37246	324
1984-022E	URS	Fragment /Cosmos 1540/	635.7	47.4	35994	232
088A	USA	CCE	939.5	2.9	49730	1063
088B	D	IRM 1	2653.4	27.0	113818	402
088C	G	UKS	2659.6	26.9	113417	1002
088F	USA	Rocket	925.2	27.2	49421	724
093G	USA	Rocket /Telstar 3C/	667.1	25.4	37485	338
113D	USA	Rocket /Anik D2/	635.9	25.7	35863	373
114C	ESA	Rocket Ariane 3-02	634.3	6.9	35841	310
115C	USA	Rocket /NATO 3D/	648.1	22.8	36505	355
1965-015C	ESA	Rocket Ariane 3-03	633.0	7.3	35803	279
048F	USA	Rocket /Morelos 1/	635.3	25.9	35825	337
048H	USA	Rocket /Telstar 3D/	661.0	26.1	37139	377
076E	USA	Rocket /Aussat 1/	641.8	26.1	36109	429
076G	USA	Rocket /ASC 1/	637.9	26.7	35900	437
109F	USA	Rocket /Morelos 2/	650.4	26.1	36608	370
1985-109G	USA	Rocket /Aussat 2/	647.4	26.4	36441	379
1986-082D	URS	Fragment /Raduga 19/	637.1	45.9	36043	252
082E	URS	Rocket	638.9	46.6	36253	135
1987-028E	URS	Rocket /Raduga 20/	635.6	47.4	35901	318
029C	USA	Rocket /Palapa B-2P/	641.5	24.4	36281	238
070C	J	Rocket /ETS 5/	649.4	27.8	36693	230
073E	URS	Rocket /Ekran 16/	627.3	47.3	35530	258
073F	URS	Fragment	628.4	47.3	35522	327
078C	ESA	Rocket Ariane 3-07	645.6	6.8	36483	250
078D	ESA	Fragment	627.0	6.9	35555	218
